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FORAMINIFERA, ORANGE COUNTY OUTFALL AREA, CALIFORNIA

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FORAMINIFERA, ORANGE COUNTY OUTFALL AREA, CALIFORNIA[1]

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by

Orville L. Bandy, James C. Ingle, Jr., and Johanna M. Resig

Allan Hancock Foundation

University of Southern California

Los Angeles, California

July 6, 1964

FPWCA

[1]Contribution from the Allan Hancock Foundation. This investigation was supported in large part by U. S. Public Health Service Research Grant WP-00158-05A1, from the Division of Water Supply and Pollution Control.

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ABSTRACT

Population patterns of foraminifera, normally parallel to the shoreline, are altered by the discharge of sewage in the area of the Orange County outfall. Specimens of planktonic and certain benthic species are many times as abundant near the outfall as in unaffected areas, producing a significant abundance aureole around the discharge point. The planktonic abundance is apparently in response to increased nutrients and phytoplankton productivity near the outfall. Calcareous perforate foraminifera are more than 8 times as abundant as other types over most of the shelf area in the living population; somewhat greater prominence of arenaceous types in the dead assemblages of the central shelf suggests the calcareous forms are undergoing gradual postdepositional solution.

Buliminella elegantissima (d'Orbigny) is the dominant calcareous foraminifer of the abundance aureole and beneath the main track of the sewage field. Arenaceous forms, Trochammina and Eggerella, are most abundant on silty sand and appear to be controlled by sediment type. A Nonionella group, normally abundant on the shelf, is adversely affected by the outfall. Bulimina marginata denudata Cushman and Parker shows an increase in abundance with nitrogen content of the sediments; based upon studies of larger outfalls, this species and polychaetes will expand in the outfall area with future increases in volume of effluent.

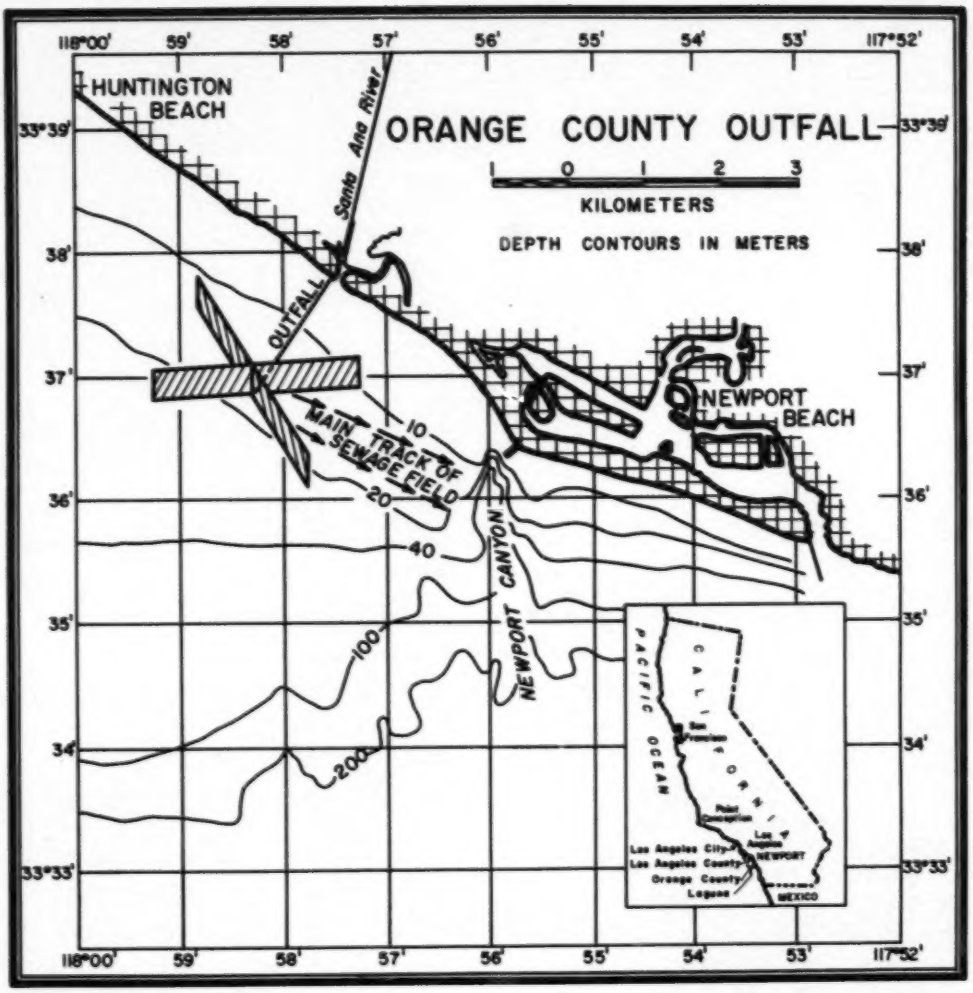
INTRODUCTION

Coastal areas of California are faced with the introduction of ever-increasing volumes of sewage (effluent) into coastal waters by ocean outfalls. It is important to understand how pollution is affecting marine life at present. Future changes, because of this increase in effluent, may be partially anticipated by evaluating larger existing outfalls. Foraminifera, marine protozoans with a test or shell of either calcium carbonate or of foreign particles, are dominant constituents of sediments on the mainland shelf and provide one ideal means of demonstrating relationships between marine animals and ocean pollution.

A volumetrically important sewage outfall in southern California is located near Newport Beach in Orange County (Fig. 1). It was constructed in 1954 with a design capacity of nearly 800 x 10^6 liters per day and it now has an average flow of about 284 x 10^6 liters per day. This is 75 times the volume of the Laguna Beach outfall, some 22 km to the south, and it is about one fourth the volume of the Los Angeles County and City outfalls to the north; thus, it is intermediate in size. The waste is both domestic and industrial primary chlorinated effluent with a pH of 7.1 (Engineering-Science, Inc. 1961). Length of the outfall pipe is about 2064 m and the water depth of the discharge point is approximately 18 m. It is important to note that the water depth at the Orange County outfall is about one third that of the Los Angeles County outfall, although discharge occurs at a similar distance offshore. Further, the Los Angeles County outfall area is off a headland whereas the Orange County outfall area is bordered by a lowland.

The mainland shelf of this study, a southeastern extension of

FIG. 1. Orange County outfall area, showing stations, bathymetry (meters), and relationship to other outfalls.


ORANGE COUNTY OUTFALL
HUNTINGTON BEACH
Santa Ana River
OUTFALL
NEWPORT BEACH
MAIN TRACK OF SEWAGE FIELD
NEWPORT CANYON
10
20
40
100
200
0 1 2 3
KILOMETERS
DEPTH CONTOURS IN METERS
118°00'
59'
58'
57'
56'
55'
54'
53'
117°52'
33°39'
38'
37'
36'
35'
34'
33°33'
PACIFIC OCEAN
CALIFORNIA
San Francisco
Point Conception
Los Angeles
NEWPORT
Los Angeles City
Los Angeles County
Orange County
Laguna
MEXICO

San Pedro Shelf, embraces an area 17 km long, 3 km wide on the southeast, and more than 9 km wide on the northwest (Fig. 1). As on the north, the shelf break is at depths of between 70 and 100 m. Newport Canyon incises the shelf to the south of the outfall and it exerts a significant influence on local current patterns and upwelling.

Sampling control is based upon 65 stations, with close spacing near the outfall. Foraminiferal samples were collected with a Hayward orange-peel grab and preserved in alcohol. Rose bengal, a protein-specific stain, was added to stain the protoplasm of live specimens. Live specimens were those with a bright red stain in the final chamber (calcareous forms) or at the aperture (arenaceous forms).

Many thanks are due Dr. R. E. Stevenson, who was concerned with the early development of the program; to Dr. Olga Hartman, who provided megafaunal data; to Richard Anderson, Robert A. P. Gaal, Robert Lessard, Gertrude Mahn, William Polski, Kurt Rottweiler, Detlef Warnke, and Mary Wittington for technical assistance; to R. K. Stouffer, for drafting; to Mrs. Barbara Lidz, for drawing figures of the foraminifera; to Maynard T. Smith, for editorial and typing assistance; to Captain G. Allan Hancock and members of the crew of R/V VELERO IV, who made possible the shipboard operation; to Mr. Curtis Miller, for assistance in computer programming; and to the Western Data Processing Center at the University of California at Los Angeles, for computer time on the IBM 7090.

This investigation was supported in large part by U. S. Public Health Service Research Grant WP-00158-05, from the Division of Water Supply and Pollution Control. Some of the shipboard time was supported by the California State Water Pollution Control Board.

PREVIOUS WORK

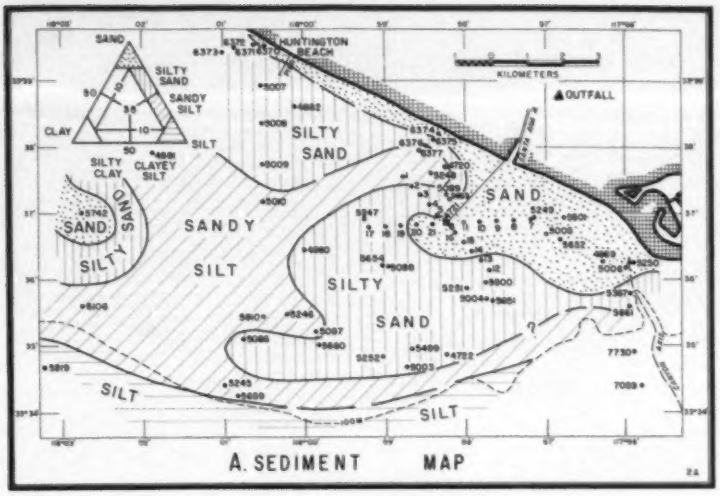
Earlier studies of foraminiferal ecology of southern California include the two categories, those of general patterns of distribution and those identified with outfall studies. In the general category are those works of Natland (1933), Crouch (1952), Bandy (1953), Walton (1955), Reiter (1959), Uchio (1960), Cooper (1961), Bandy (1963), and Bandy, Ingle, and Resig (1964c). Studies of foraminifera related to ocean outfalls include those of Zalesny on Santa Monica Bay and the Hyperion outfall area (1959), Resig on southern California outfalls in general (1960), Watkins on Orange County outfall (1961), and the more recent works by Bandy, Ingle, and Resig on the Laguna Beach and Los Angeles County outfalls (1964a, b). All but the latter two analyzed dead and live foraminiferal specimens together, showing a dominance of certain arenaceous species near the outfalls. Separate analyses of live and dead populations have shown the reverse to be true as demonstrated in the studies of Laguna Beach and Los Angeles County outfalls.

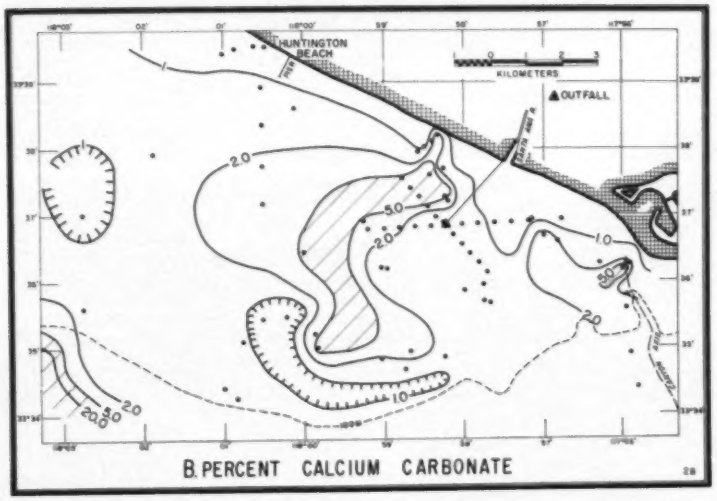
SUBSTRATE AND OCEANOGRAPHY

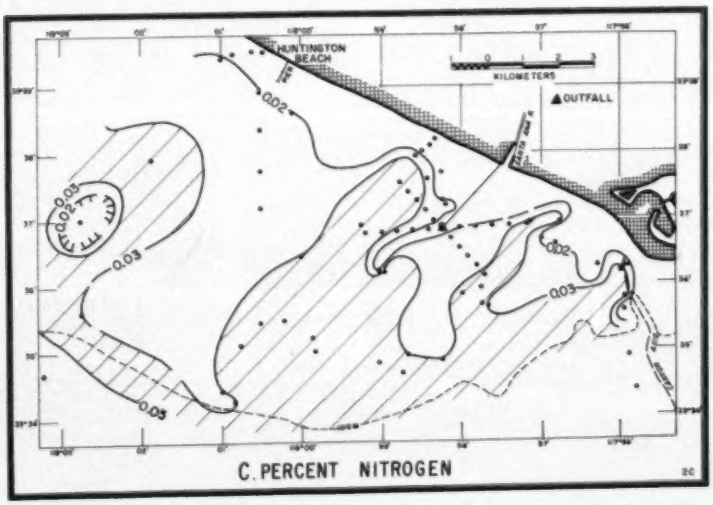
Most of the sediments of the shelf near the Orange County outfall are medium to fine olive green sands and silts (Stevenson, Uchupi, and Gorsline 1959); sands are dominant in the inshore zone, sandy silts and silty sands occur on the open shelf, and silts prevail in the bathyal zone (Fig. 2A). Coarser sediments near the outfall are largely derived from the Santa Ana River. Percentages of calcium carbonate, determined gasometrically (Bien 1952), are generally less than 2% excepting in a central area where values in excess of 5% occur (Fig. 2B). Just to the north, better control shows a dramatic increase in calcium carbonate with increasing depth; values are about 2% on the shelf and 20% or more at the edge of the shelf and in deeper waters (Bandy, Ingle, and Resig 1964c). Relict Pleistocene fossils appear to be very rare in the area of the outfall. Percentages of nitrogen (Fig. 2C), using the standard micro-Kjeldahl method of analysis (Kabat and Mayer 1961), show a general inverse relationship with grain size, as reported by Emery and Niino (1963) for the Gulf of Thailand and as found on San Pedro Shelf to the north (Bandy, Ingle, and Resig 1964c). Higher values occur generally in silty sands and sandy silts of the central and outer shelf areas off the end of the Orange County outfall.

Median annual surface temperatures are about 17C (Stevenson 1962); water temperatures at 100 m are about 9-10C (Emery 1960). Near the outfall, two types of temperature profiles are known: summer temperatures produce a layer of warm water over cooler subsurface water, winter temperatures are nearly the same throughout the water column (Watkins 1961). Temperatures at the outfall are generally 1 or 2 degrees higher than the surrounding surface temperatures (L. Lidz,

FIG. 2. Characteristics of the substrate. A. Sediment distribution. B. Percentage of calcium carbonate in sediment. C. Percentage of nitrogen in sediment.


SAND
SILTY SAND
SANDY SILT
CLAY
SILT
SILTY CLAY
CLAYEY SILT
HUNTINGTON BEACH
KILOMETERS
OUTFALL
SILTY SAND
SAND
SANDY SILT
SILT
SILTY
SAND
SILT
SILTY
SAND
SILT
SILT
SILT
A. SEDIMENT MAP


HUNTINGTON BEACH
KILOMETERS
OUTFALL
2.0
5.0
2.0
1.0
2.0
1.0
2.0
5.0
2.0
B. PERCENT CALCIUM CARBONATE


HUNTINGTON BEACH
KILOMETERS
OUTFALL
0.02
0.03
0.02
0.03
0.02
0.03
0.03
C. PERCENT NITROGEN

personal communication).

Salinities are about 33.5‰ near the outfall area and increase to about 33.9 ‰ seaward toward the edge of the shelf (L. Lidz, personal communication). Compounds of phosphorous, silicon, and nitrogen are many times as abundant near the outfall as in normal shelf waters; values decrease rapidly away from the outfall, becoming normal at a distance of about 1000 m from the outfall (Stevenson and Grady 1956).

Currents, in the Newport Beach region, are usually directed southeastward, parallel to the coast; however, a landward drift occurs when southeasterly winds blow for more than 10 hours, when there is unequal tidal stirring over Newport Canyon, or when eddies circulate around the Palos Verdes headland with increased frequency (Stevenson 1963). An investigation of the sewage field and the diffusion of wastes from the orange County outfall shows a definite movement of the effluent southeastward toward Newport Canyon, more or less parallel to the coast (Tibby, Foxworthy, Oguri, and Fay 1964). It is likely that upwelling occurs with some frequency in Newport Canyon (Emery and Hülsemann 1963; Allan Hancock Foundation 1963), introducing cooler, nutrient-rich waters into the photic zone and contributing to the dispersal of the sewage field. Often, the effluent field breaks up and becomes discontinuous over Newport Canyon. Rittenberg, Mittwer, and Ivler (1958) have reported very high concentrations of coliform bacteria in sediments around the outfall and especially beneath the main track of the sewage field.

FAUNAL-OUTFALL RELATIONSHIPS

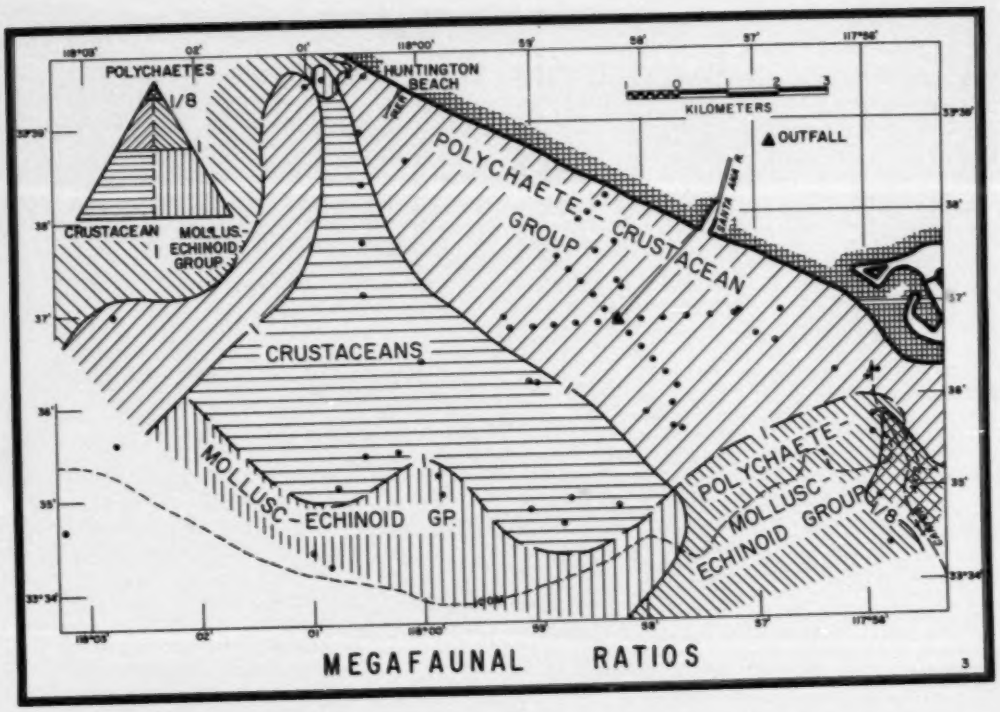
General trends

As in preceding studies (Bandy, Ingle, and Resig 1964a, b), relationships between foraminifera and ocean pollution are viewed according to general distribution patterns, specific patterns and trends, and with respect to differences between live and dead populations. Recognition of dead versus live populations conduces to recognition of relict populations, reworked fossils, and to the solution effects on living populations.

As a part of the environmental background, gross megafaunal trends were analyzed (Fig. 3). A review of data charts of Dr. Olga Hartman suggests that a three-component mapping system (Krumbein 1954) is suitable, embracing (1) polychaetes (without skeletal hardparts), (2) crustaceans (with chitinous skeletal material), and (3) the molluscan-echinoderm complex (with carbonate skeletal parts), all based upon numbers of specimens per unit volume. The outfall area and the inshore region are dominated by the polychaete-crustacean complex, the central shelf is characterized by a majority of crustaceans, and the outer edge of the shelf is dominated by molluscs and echinoderms. Newport submarine canyon has large numbers of polychaetes, similar to the Los Angeles county outfall area. It might be predicted that polychaete dominance will expand toward Orange County outfall in future years with increased volumes of effluent and an expanding sewage field.

Nektonic life is known to be significantly affected by waste discharge; SCUBA-equipped divers have observed and photographed abnormally high fish densities at the point of effluent discharge (Robert Given, personal communication). Many fishing vessels take advantage

FIG. 3. Megafaunal ratios by the trigon method. In the central region, note the gradation from polychaete-crustacean dominance inshore, to crustaceans in the central shelf area, to the mollusc-echinoid complex on the outer shelf. Plotted from data by Dr. Olga Hartman.


POLYCHAETES
1/8
CRUSTACEAN
MOLLUS.-ECHINOID GROUP
3
HUNTINGTON BEACH
KILOMETERS
OUTFALL
POLYCHAETE - CRUSTACEAN GROUP
CRUSTACEANS
MOLLUSC - ECHINOID GP.
POLYCHAETE - MOLLUSC - ECHINOID GROUP
1/8
MEGAFAUNAL RATIOS
3

of the fish concentration near the discharge point (boil). Presumably the fish congregate at the outfall in response to abundant food!

General foraminiferal abundance reflects a definite relationship to the position of the outfall in both total and live population patterns (Figs. 4A, 4B): an irregular depression zone surrounds the immediate outfall point and an abundance aureole borders the depressed zone, especially along the outer (seaward) edge. It is likely that increasing effluent will eventually produce a prominent dead zone, for benthic foraminifera, beneath the sewage field in a manner like that now existing beneath the sewage field of the Los Angeles County outfall (Bandy, Ingle, and Resig 1964b). The abundance aureole, especially on the seaward side of the outfall, contrasts with the lower values over most of San Pedro Shelf to the north (Bandy, Ingle, and Resig 1964c); high values seaward off the edge of the shelf probably exist, but more control is needed for substantiation.

Live/dead ratios are highest in a number of limited areas parallel to the coastline and at the same depth as the outfall (Fig. 4C); this trend continues northward in the San Pedro area as well. Higher values may reflect somewhat higher rates of deposition (Phleger 1960); however, perhaps they reflect conditions of prominent sediment transport.

Number of different species per sample, the species diversity index, reflects a marked increase, generally, in an offshore direction (Figs. 5A, 5B) in both dead and live populations of foraminifera. The abundance aureole, based upon specimens per gram, is associated with higher values for species diversity, providing a major anomaly to the normal offshore trend.

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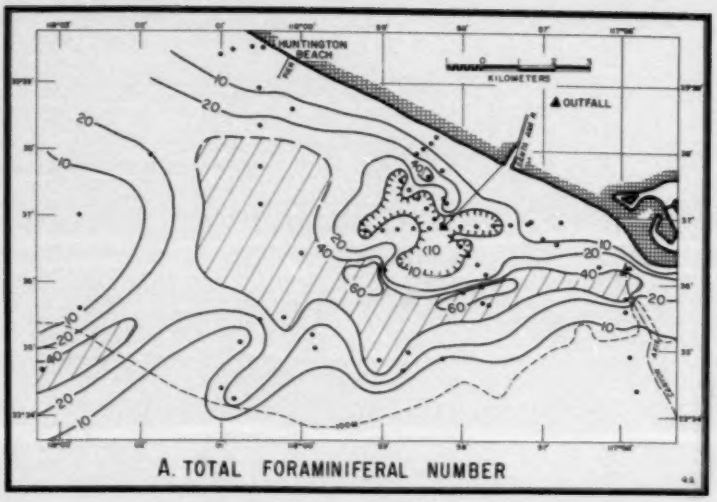
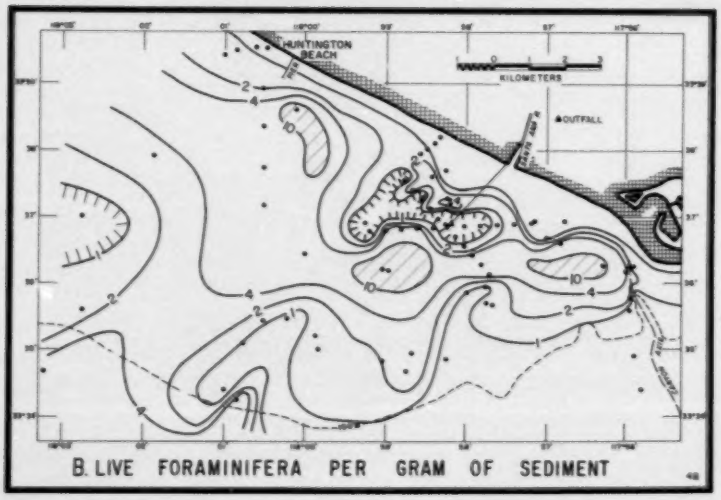
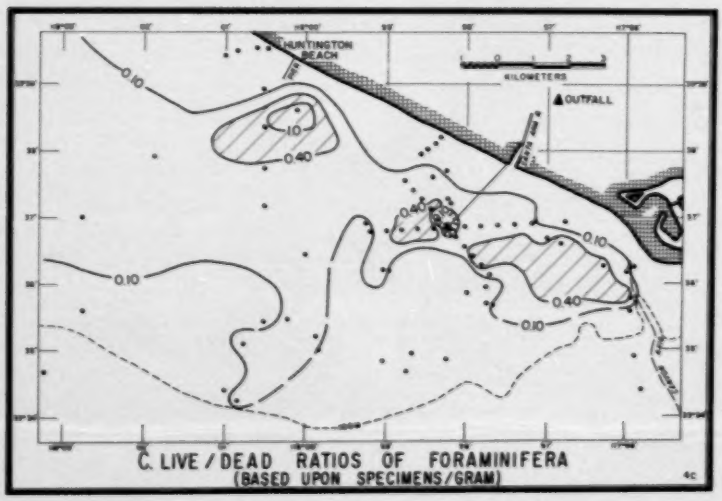
FIG. 4. General foraminiferal relationships. A. Total foraminifera/g of dry sediment. Note depression zone bordered by the cross hatched abundance zone. B. Number of live benthic specimens/g of dry sediment. Note fragments of an abundance aureole 2 or 3 km from the outfall. C. Live/dead ratios of benthic foraminifera.



A. TOTAL FORAMINIFERAL NUMBER

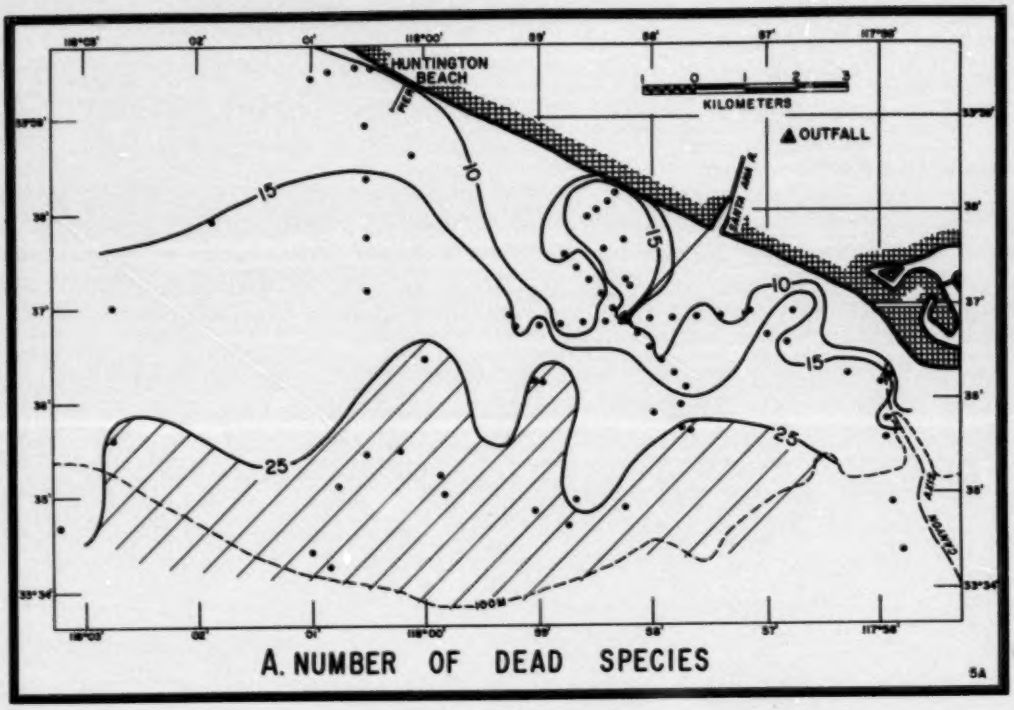


B. LIVE FORAMINIFERA PER GRAM OF SEDIMENT



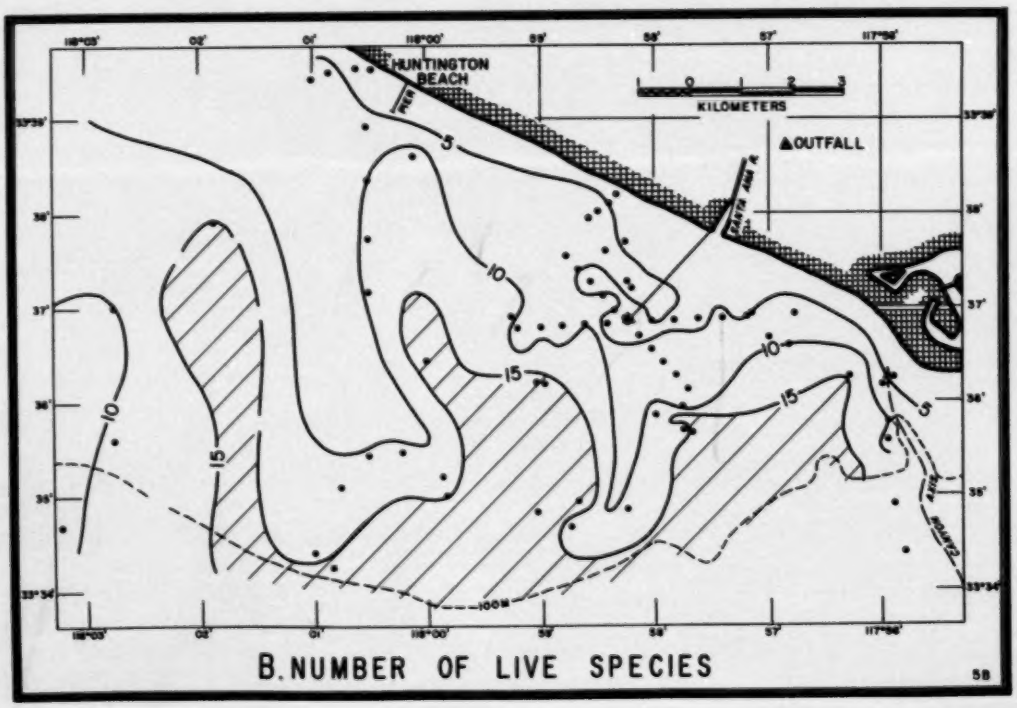
C. LIVE / DEAD RATIOS OF FORAMINIFERA
(BASED UPON SPECIMENS/GRAM)

FIG. 5. Species diversity. A. Diversity of dead species. B. Diversity of live species. Note the general increase in species away from shore, in both dead and live populations.



A. NUMBER OF DEAD SPECIES

5A



B. NUMBER OF LIVE SPECIES

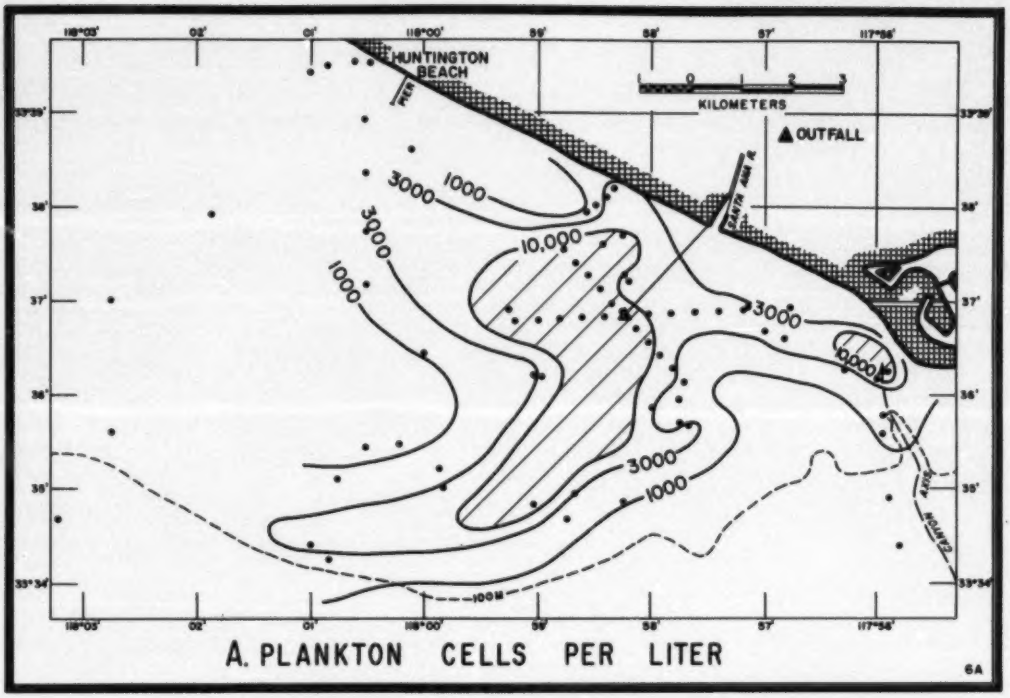
5B

Planktonic relationships

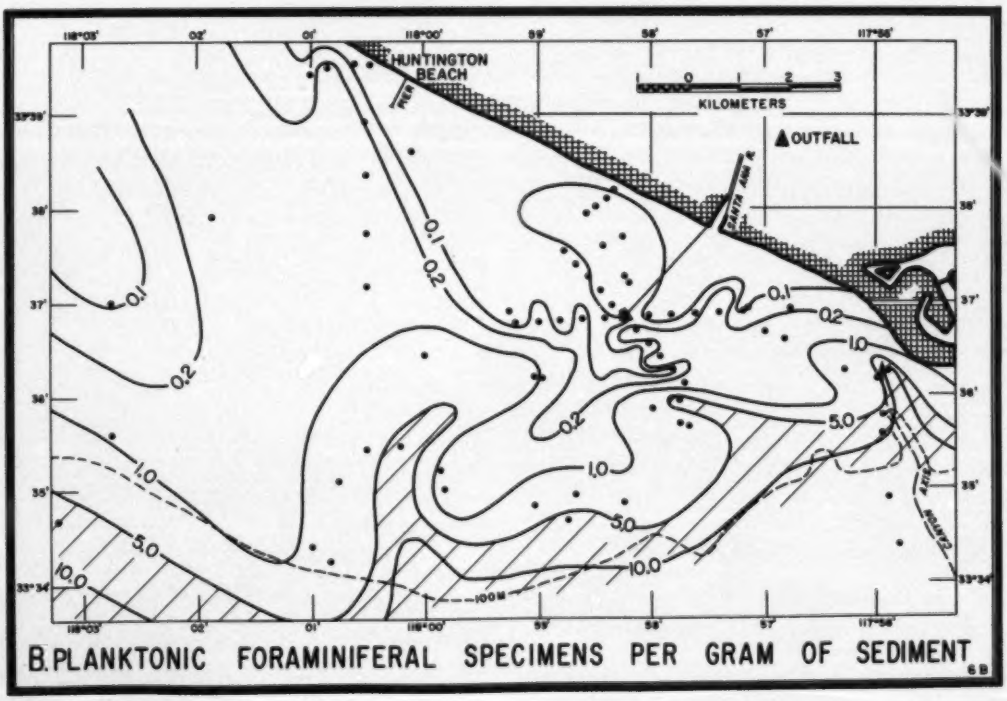
Calcareous tests of the planktonic foraminifera are invaluable indices to the character of water masses; the tests are formed in the water column and are deposited on the sea floor, leaving a permanent record of their distribution. At Orange County outfall and other outfalls studied (Bandy, Ingle, and Resig 1964a, b), concentrations of phytoplankton show a distinct increase near the discharge zones (Fig. 6A), presumably in response to the enormous influx of nutrients within the effluent. For example, phosphate, a key nutrient in the phytoplanktonic cycle, reaches concentrations of 10.0 µg-at/L within a radius of about 1000 m of the Orange County outfall boil, whereas uncontaminated waters overlying other areas of the mainland shelf have average concentrations of 0.5 µg-at/L (Allan Hancock Foundation 1963).

Planktonic foraminifera (mostly Globigerina bulloides d'Orbigny and G. quinqueloba Natland) depend upon other planktonic cells for food (Bé 1960); thus, an increase in phytoplankton can be expected to cause an increase in abundance of planktonic foraminifera. The abnormally high concentrations of planktonic foraminifera in sediments beneath the Orange County outfall area suggest that such a sympathetic food chain of increased nutrients, phytoplankton, and finally planktonic foraminifera is in operation in direct response to the outfall. This is corroborated by evidence of a zone of high plankton productivity in an aureole about the outfall (Tibby, Foxworthy, Oguri, and Fay 1964). Peak productivity, as measured by uptake of radioactive carbon, was recorded at a radial distance of between 1.0 and 2.0 km from the boil, with one exceptionally high number adjacent to the effluent boil. The abundance of planktonic

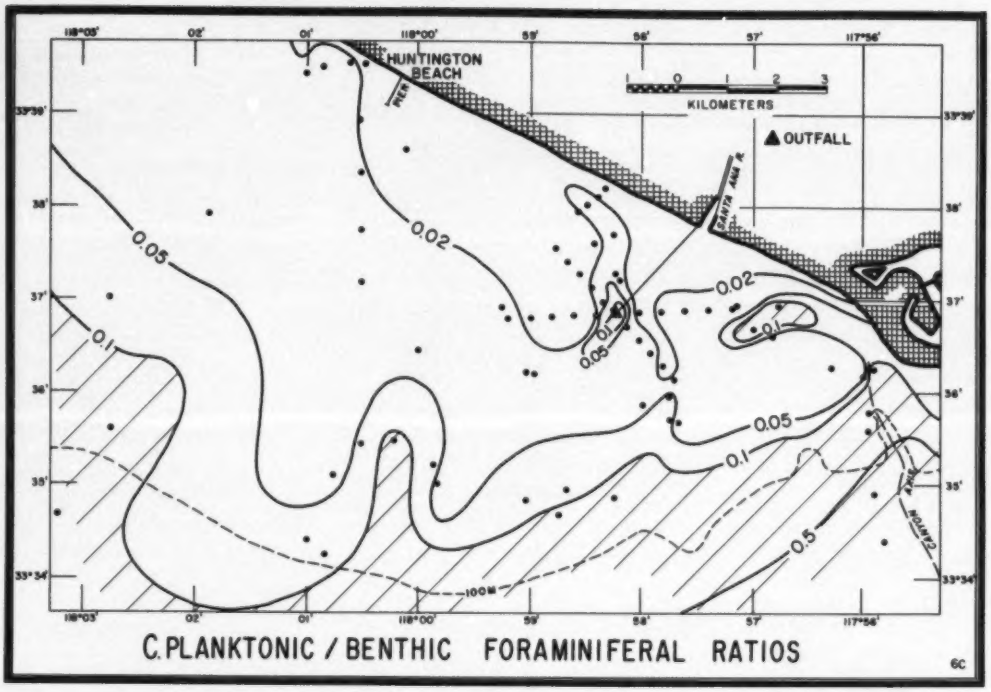
FIG. 6. Planktonic relationships. A. Cells of plankton/liter, total for the water column. Data collected between 1956 and 1959. Note area of high values off the end of the outfall. B. Planktonic foraminifera/g of dry sediment. Note the abrupt increase near the outer edge of the shelf. C. Planktonic/benthic foraminiferal ratios. D. Trigon analysis of arenaceous-planktonic-calcareous benthic foraminiferal relationships.



A. PLANKTON CELLS PER LITER

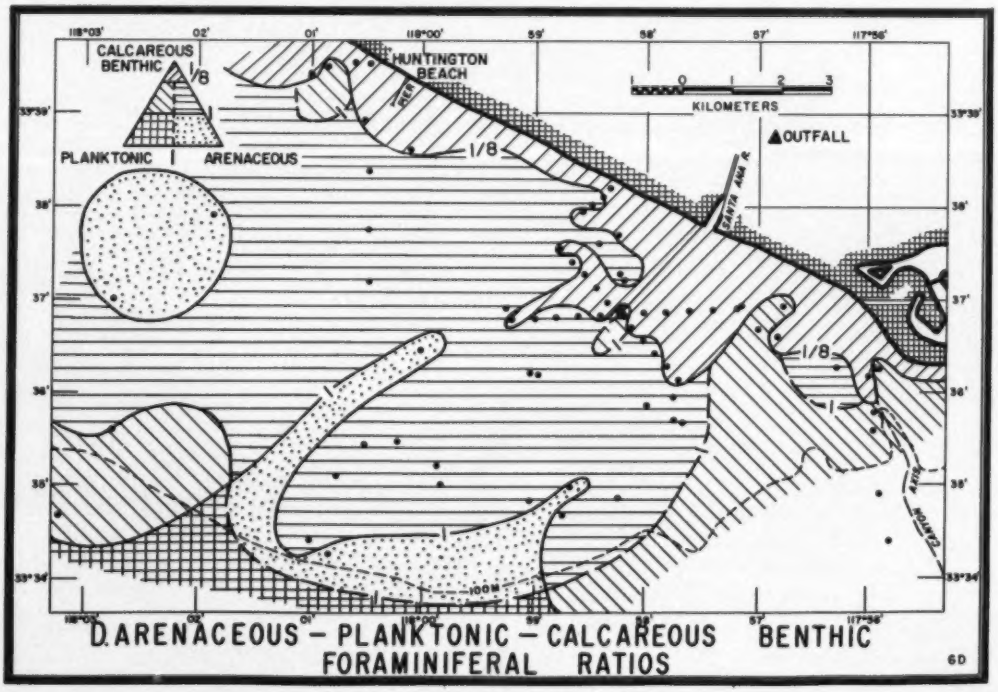


B. PLANKTONIC FORAMINIFERAL SPECIMENS PER GRAM OF SEDIMENT



C. PLANKTONIC / BENTHIC FORAMINIFERAL RATIOS

6C



D. ARENACEOUS – PLANKTONIC – CALCAREOUS BENTHIC FORAMINIFERAL RATIOS

6D

foraminifera in the sediments near the boil area are likely related to high productivity near the boil, as represented by the one exceptionally high number. An alternate explanation of abundant planktonic tests near the outfall is a high kill-off rate there; however, studies of live planktonic foraminifera in the waters surrounding the outfall do not corroborate this, as indicated by current studies by L. Lidz (personal communication). He finds greater abundances of living specimens in the waters surrounding the outfall and in the Newport Canyon area than elsewhere on the shelf.

In shelf sediments beneath uncontaminated waters, planktonic foraminiferal tests increase markedly with increasing depth to the outer edge of the shelf (Bandy, Ingle, and Resig 1964c); in the area of Orange County outfall, higher values extend irregularly into the shallower waters near the outfall (Fig. 6B). Also, planktonic/benthic ratios are highest along the outer edge of the shelf and in localized patches at the outfall and southward to the head of Newport Canyon (Fig. 6C), a trend corresponding generally to the main track of the sewage field. This suggests a correlation between chemistry of the effluent and planktonic life. High values in the canyon head may be due to upwelling of cold nutrient-rich waters there.

Productivity in the water column appears to be related to productivity of foraminifera on the ocean floor in the coastal waters of this study. Abundances of phytoplankton occur in the same general areas as abundances of benthic groups around the Orange County outfall, at the Laguna Beach outfall (Bandy, Ingle, and Resig 1964a), and in the area of the Los Angeles County outfall (Bandy, Ingle, and Resig 1964b). Complexity of the interrelationships of foraminifera to food

sources is highlighted by studies by Freundenthal, et al. (1964) in which it is shown that some foraminiferal species, perhaps most, are extremely specific in selection of food; a particular foraminifer may eat only one species of diatom or other protistid. Thus, abundance or depletion of a particular food cell would greatly affect abundance of the corresponding foraminiferal species. Certain species of benthic foraminifera dominate the benthic aureole and two species of dinoflagellates (Gonyaulax polyhedra Stein and Prorocentrum micans Ehrenbach) dominate the water column. The depressed zone of low values within the abundance aureoles of planktonic and benthic foraminifera are due possibly to large amounts of suspended detritus released at the outfall and/or toxic concentrations of some elements and compounds in the effluent. It is possible that toxicity of Gonyaulax polyhedra (Schradie and Bliss 1962) may play an important part in periodic killing of planktonic foraminifera.

Cumulative effects of foraminiferal productivity are reflected in the biofacies patterns of the sea floor. Trigon analysis is a convenient way of illustrating relationships of the three categories: planktonic tests, arenaceous tests, and calcareous benthic tests (Fig. 6D). Planktonic tests are considered to be dominant off the edge of the shelf, based upon studies of adjacent areas (Bandy, Ingle, and Resig 1964c); they are of secondary importance in localized areas of the inner shelf off Huntington Beach, at the outfall, and under the general track of the sewage field toward Newport Canyon. Arenaceous types are dominant in localized areas of the central and outer shelf; however, they are of secondary importance to the calcareous benthic group over much of the central and outer shelf area. Calcareous benthic tests are more

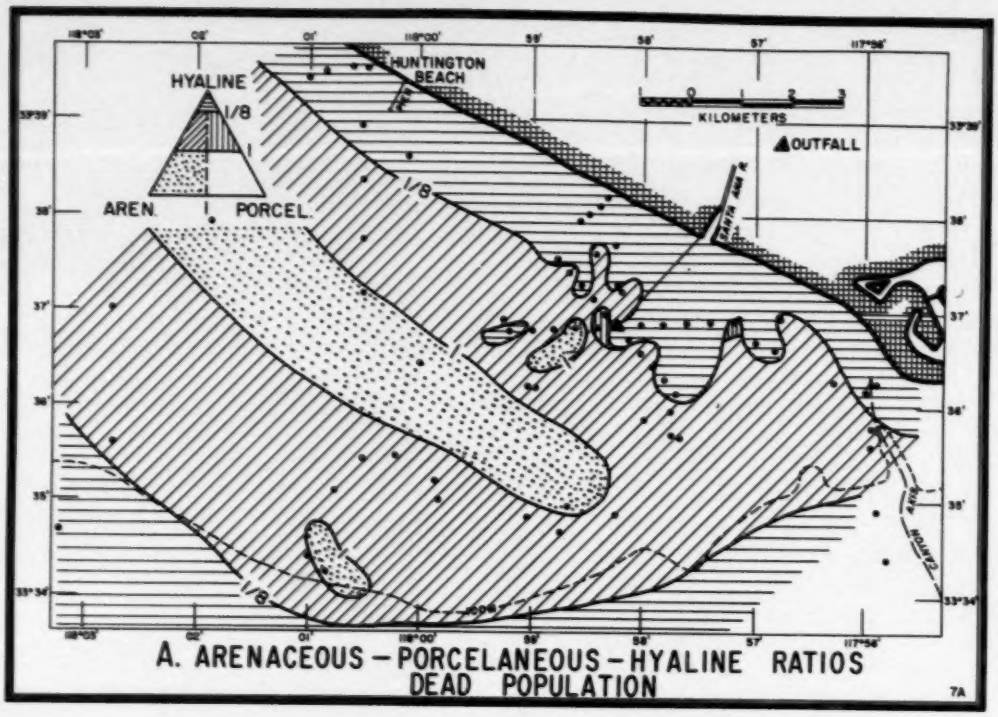
than 8 times as abundant as the other categories in the inner shelf area and near the outfall; they are more abundant than the other types over most of the area of the shelf. With increased effluent, in future years, it is likely that total populations will be largely arenaceous under the sewage field as a result of reduced pH and resulting solution of calcareous tests, as now occurs under the sewage field of the Los Angeles County outfall area (Bandy, Ingle, Resig 1964b).

Arenaceous-porcelaneous-hyaline groups

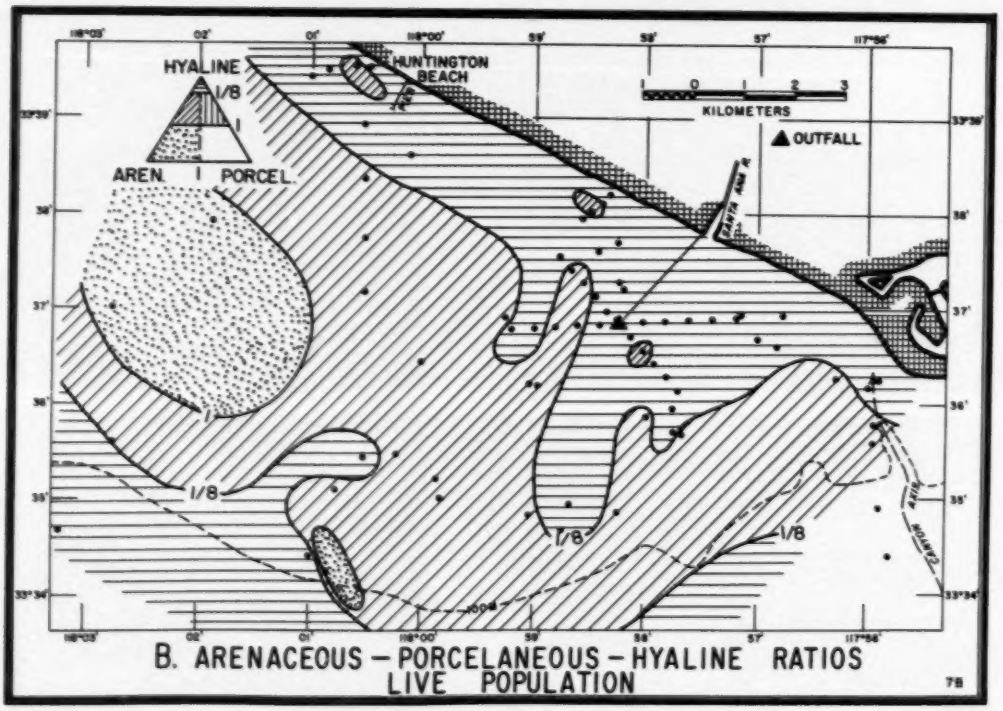
Benthic foraminifera are divisible into three groups, based upon the general nature of the test: (1) agglutinated or arenaceous tests, (2) porcelaneous tests (mostly miliolids), and (3) hyaline or calcareous perforate tests as used herein. Miliolids are especially indicative of inshore facies in tropical and warm temperate areas; agglutinated or arenaceous tests of some species are especially abundant in certain paralic environments (marshes), other arenaceous species are common on the shelf, and still others are quite distinctive of deeper water areas; hyaline types are generally the most abundant smaller foraminifera in normal marine environments (Bandy 1960).

Trigon analysis is most suitable for illustrating the dominant foraminiferal patterns according to general wall structure (Figs. 7A, 7B). Dead populations show that inshore and shelf-edge populations have more than 8 times as many hyaline specimens as other types; a long central zone is dominated by arenaceous types, and these decrease in abundance both inshore and offshore. Arenaceous types are dominant also in a small area off the end of the outfall; they are of significance on sand, silty sand, and sandy silt substrates! Live populations reveal

FIG. 7. Trigon analysis of arenaceous-porcelaneous-hyaline foraminiferal groups. A. Analysis of dead population. B. Analysis of live population.



A. ARENACEOUS – PORCELANEOUS – HYALINE RATIOS
DEAD POPULATION



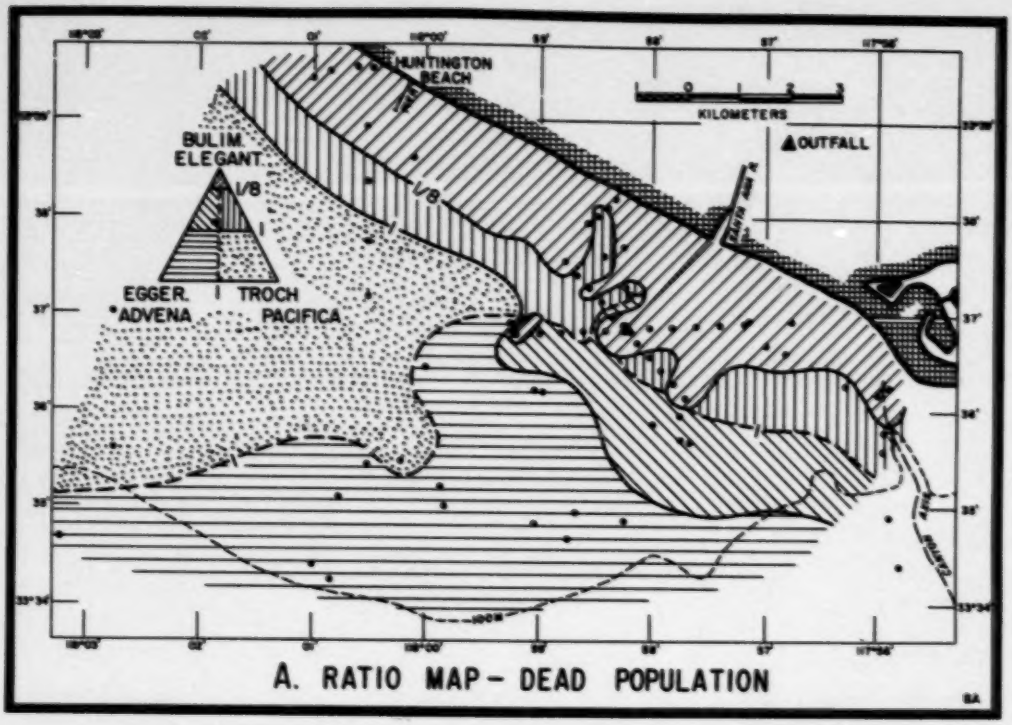
B. ARENACEOUS – PORCELANEOUS – HYALINE RATIOS
LIVE POPULATION

a spectacular change in which the hyaline group is more than 8 times as abundant as other groups over a much expanded area in the outfall area, a phenomenon also well illustrated in the area of the Los Angeles County outfall (Bandy, Ingle, and Resig 1964b). This suggests there is solution of calcareous tests in the central area of the shelf or there has been a very recent major increase in calcareous hyaline populations not yet reflected correctly by dead assemblages.

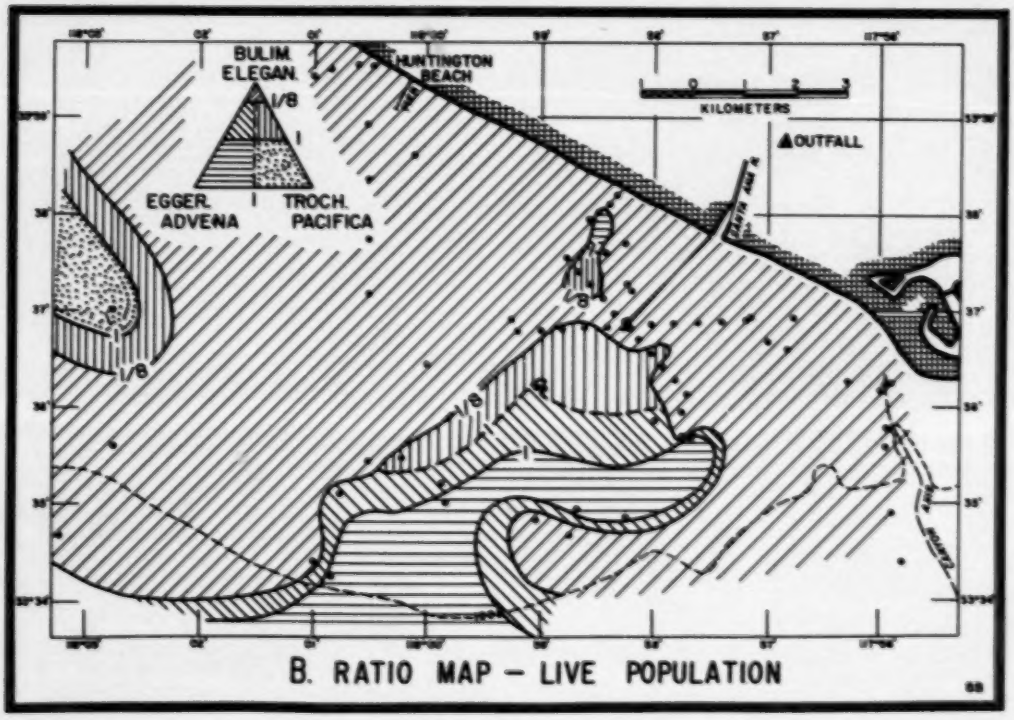
Relationships of species and species groups to ocean pollution

In a number of reports (Zalesny 1959, Resig 1960, Watkins 1961), two arenaceous species proved to be most significant in outfall areas of southern California. A third species, Buliminella elegantissima (calcareous, perforate), was found to be especially prominent in the Laguna Beach and Los Angeles County outfall areas in more recent investigations (Bandy, Ingle, and Resig 1964a, b). These three dominant forms provide a convenient three-component system for trigon analysis of both dead and live populations (Figs. 8A, 8B). In the dead population, Buliminella elegantissima dominates on the inner half of the shelf and is more than 8 times as abundant as the others in the inner portion of this zone; Eggerella advena is most abundant in central and outer shelf areas, primarily on the silty sand substrate; and Trochammina pacifica is most abundant in the central and outer shelf area, primarily on a sandy silt substrate. In the live population, Buliminella elegantissima is more than 8 times as abundant as either of the other forms over most of the shelf and certainly under the entire area of the sewage track!

FIG. 8. Trigon analysis of three dominant species: Buliminella elegantissima, Eggerella advena, and Trochammina pacifica. A. Dead population. B. Live population. Note increased prevalence of Buliminella elegantissima in the live population.



A. RATIO MAP – DEAD POPULATION

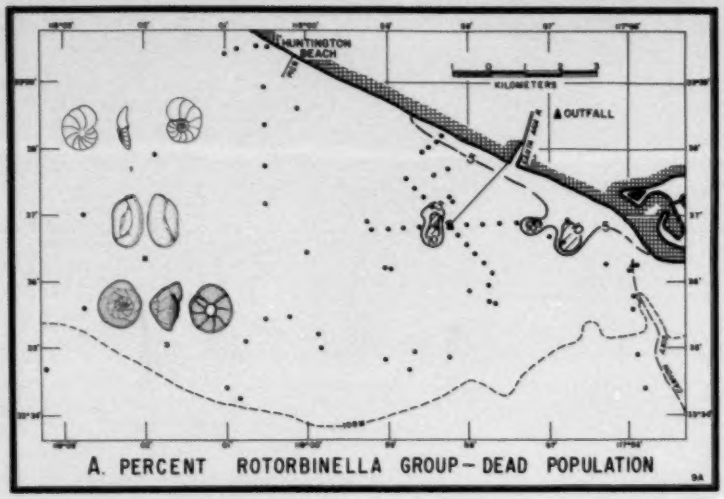


B. RATIO MAP – LIVE POPULATION

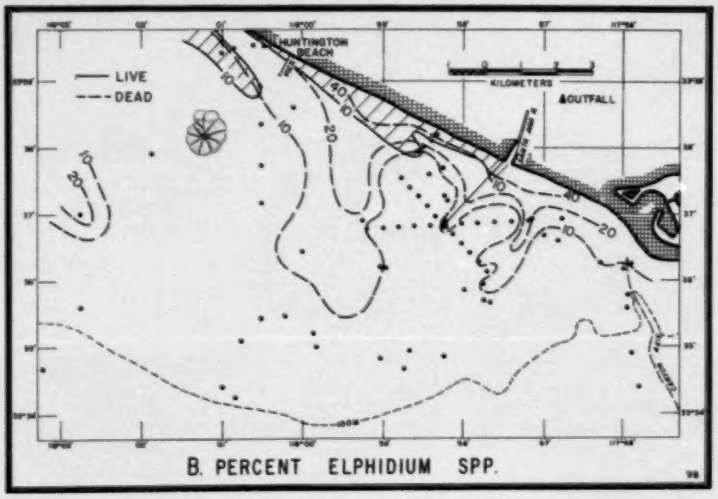
An inshore paralic faunal group, the Rotorbinella group (Fig. 9A), is quite specific for the littoral and marginal sublittoral zone in both live and dead populations. This is consistent with the occurrence of this group to the north (Bandy, Ingle, and Resig 1964b) and in general for southern California (Bandy 1963). A second inshore index is the Elphidium group (Fig. 9B); dead populations are distributed somewhat more widely than the highly restricted living population.

Buliminella elegantissima is the most significant member of the foraminifera in the outfall area of Orange County for three reasons: (1) the midpoint of its depth range (about 18 m) coincides with that of the outfall, (2) it is the most abundant member, making up between 50 and 80 percent of the total population along a broad belt parallel to the shore and embracing the outfall, and (3) it has shown a marked positive response to outfalls at Laguna Beach and Los Angeles County (Bandy, Ingle, and Resig 1964a, b). Relatively, this species comprises more than half of the fauna in much of the inshore area of this investigation (Fig. 9C). Its prominence is even more striking in the live population, it comprises from 50 to more than 90 percent of the foraminifera around the outfall and beneath the main track of the sewage field southward to Newport Canyon (Fig. 9D)! An anomalous occurrence was noted in one sample along the outer edge of the shelf, an occurrence similar to that noted along the edge of the San Pedro Shelf to the north (Bandy, Ingle, and Resig 1964c). Absolute values for occurrence are worthy of note for this species; values for specimens/g in both dead and live populations show a significant abundance in the form of an aureole around the outfall and toward the Newport Canyon area (Figs. 9E, 9F), and on both sand and silty sand substrates.

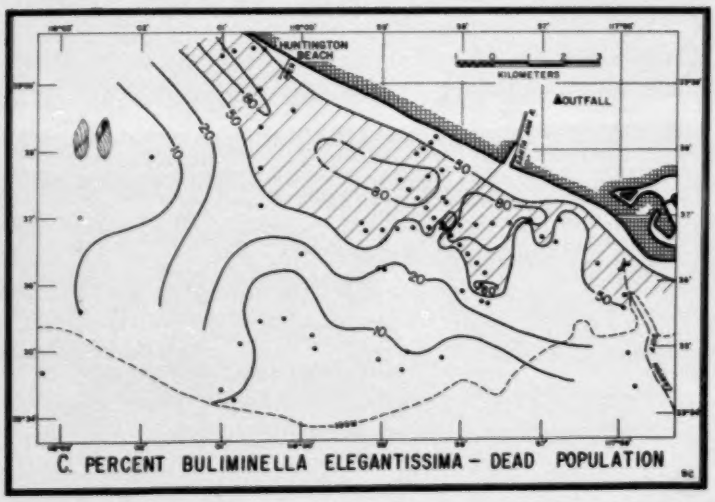
FIG. 9. Distribution of individual species and species groups. A. Distribution of Rotorbinella group (1. Cibicides fletcheri Galloway and Wissler, 2. Quinqueloculina akneriana d'Orbigny vars., 3. Rotorbinella lomaensis [Bandy]). B. Distribution of Elphidium spp. Note restriction of the dominant live population (cross hatched area) to inshore area. Distribution of Buliminella elegantissima: C. % dead population; D. % live population; E. dead specimens in no/gm of dry sediment; F. live specimens in no/gm dry sediment. G. Distribution of the combination of Eggerella advena (Cushman) and Trochammina pacifica Cushman (% of foraminiferal population). Distribution of Nonionella (1. N. miocenica stella Cushman and Moyer, 2. N. scapha basispinata [Cushman and Moyer]): H. % of dead population; I. % of live population. Distribution of Bulimina marginata denudata Cushman and Parker: J. % in dead and live populations; K. No/gm of dead and live populations in sediment. L. Distribution of shelf-edge group (1. Bolivina acuminata Natland, 2. Bolivina pacifica Cushman and McCulloch, 3. Epistominella bradyana [Cushman], and 4. Uvigerina juncea Cushman and Todd) in % live and dead fauna.



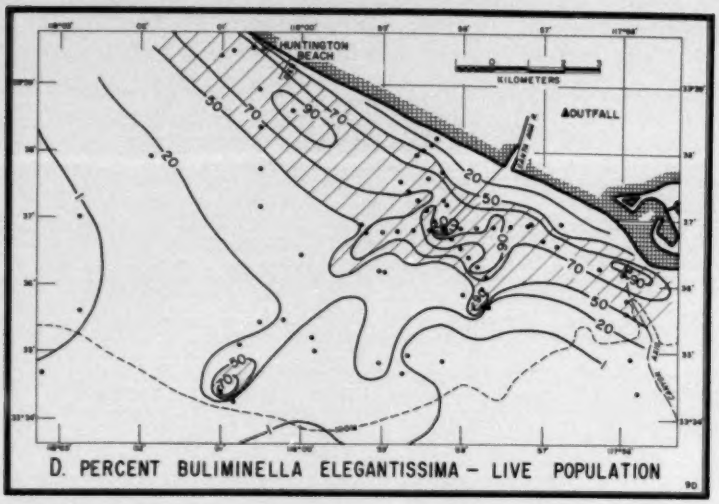
A. PERCENT ROTORBINELLA GROUP – DEAD POPULATION

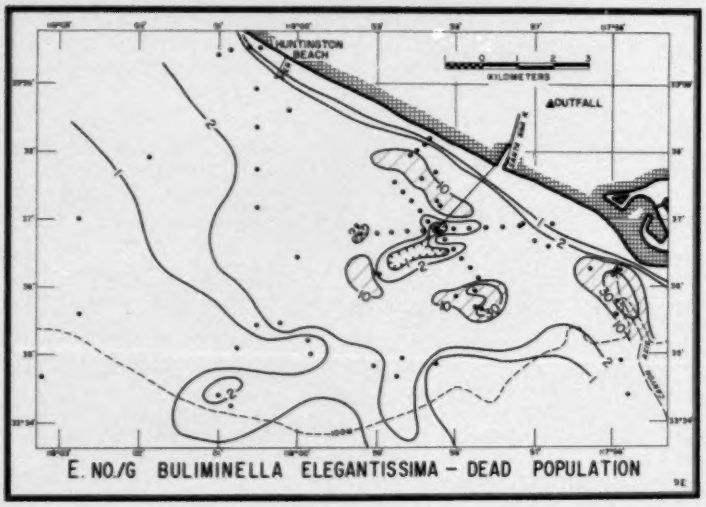


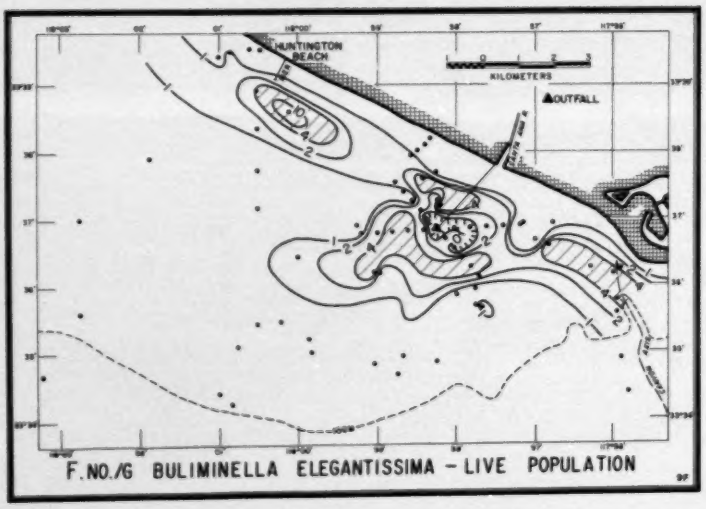
B. PERCENT ELPHIDIUM SPP.

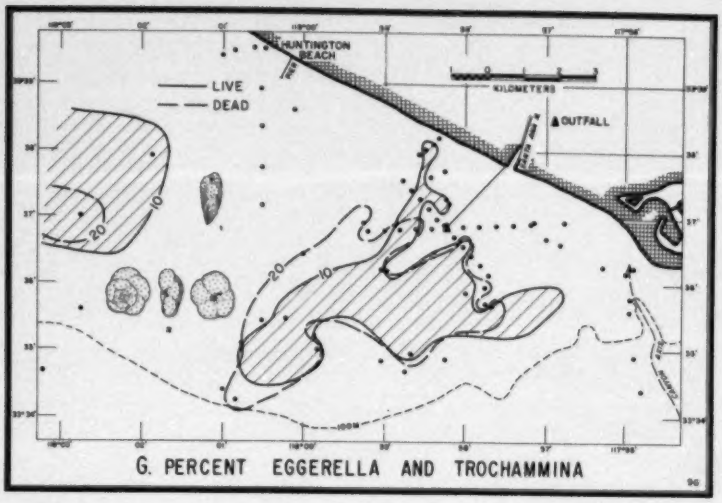


C. PERCENT BULIMINELLA ELEGANTISSIMA – DEAD POPULATION

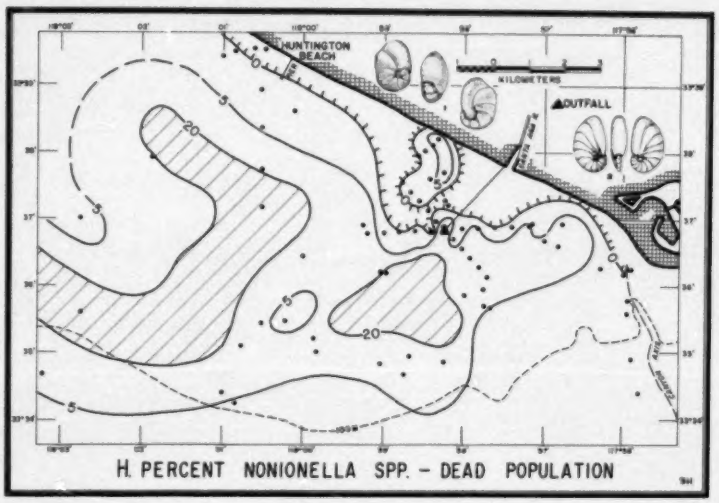

HUNTINGTON BEACH
KILOMETERS
OUTFALL
D. PERCENT BULIMINELLA ELEGANTISSIMA - LIVE POPULATION


HUNTINGTON BEACH
KILOMETERS
OUTFALL
E. NO./G BULIMINELLA ELEGANTISSIMA - DEAD POPULATION

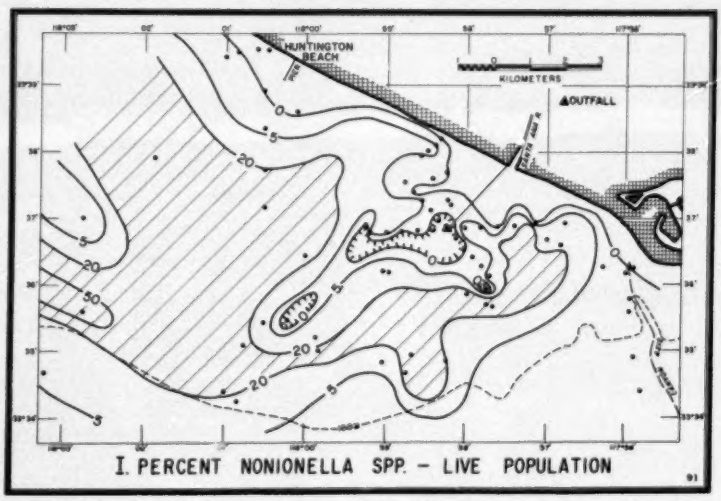

HUNTINGTON BEACH
KILOMETERS
OUTFALL
F. NO./G BULIMINELLA ELEGANTISSIMA - LIVE POPULATION



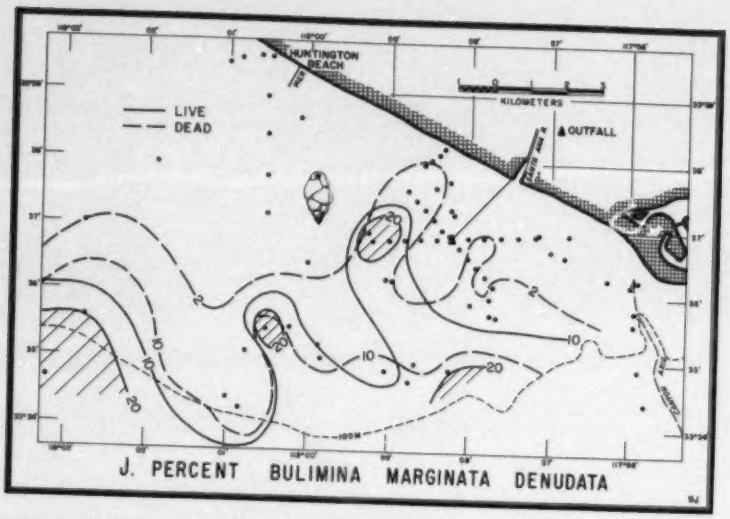
G. PERCENT EGGERELLA AND TROCHAMMINA



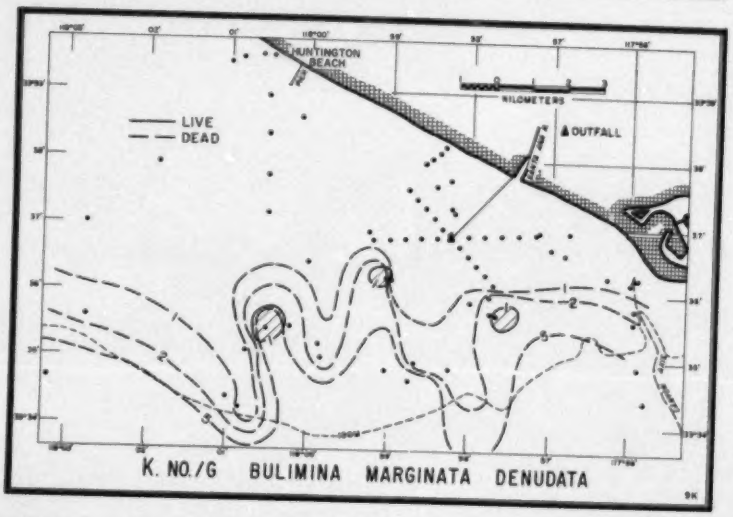
H. PERCENT NONIONELLA SPP. - DEAD POPULATION



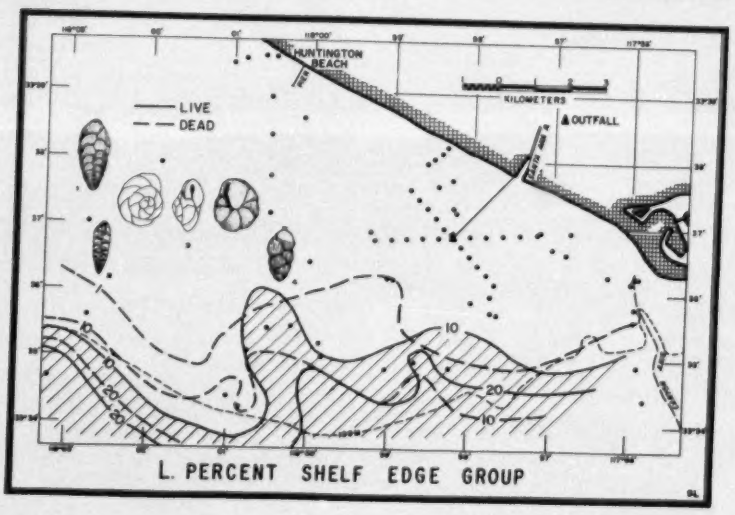
I. PERCENT NONIONELLA SPP. - LIVE POPULATION



J. PERCENT BULIMINA MARGINATA DENUDATA



K. NO./G BULIMINA MARGINATA DENUDATA



L. PERCENT SHELF EDGE GROUP

A combination of Trochammina and Eggerella, arenaceous species, comprise somewhat more than 20% of the dead population and more than 10% of the live population in a broad central area off the end of the outfall (Fig. 9G); however, this distribution is remarkably similar to the distribution of silty sand. Sediment control is indicated rather than an affinity for the outfall for two reasons: (1) abundances are associated with silty sand, and (2) the principal track of the sewage field is southeastward toward Newport Canyon, which is directed away from the area of abundant members of this group. Moreover, a recent study has related the size distribution of Eggerella advena on the mainland shelf to sediment size (Resig, 1963).

Nonionella spp have proved to be important members of the central and outer San Pedro shelf biofacies (Bandy, Ingle, and Resig 1964c); they are similarly important in the central and outer shelf area of the Orange County outfall area (Figs. 9H, 9I) in both dead and live populations. Assemblages are most abundant on sandy silts and silty sands, generally, and there is a major depression zone surrounding the general area of the outfall, especially in the living population. Relative rare occurrences of Nonionella spp were noted in the region of the Los Angeles County outfall to the north (Bandy, Ingle, and Resig 1964b); it is likely that this group will become adversely affected by increasing effluent in the Orange County outfall area.

Bulimina marginata denudata, an unusually important species in both lagoonal and shelf-edge areas of southern California (Bandy 1963), occurs in greatest frequency and in greatest values/g on different sediment types on the central and outer shelf (Figs. 9J, 9K). In this area and on San Pedro Shelf to the north (Bandy, Ingle, and Resig

1964c), the occurrence coincides directly with areas of high nitrogen values rather than with a particular sediment type; in the area of this study maximum values for occurrence of Bulimina marginata denudata are identified with nitrogen values of 0.03% or more.

A shelf-edge group of species consists of Bolivina acuminata, Bolivina pacifica, Epistominella bradyana, and Uvigerina juncea. This assemblage displays an abrupt increase from complete absence on the shelf proper to values of more than 10% in dead and live populations below the edge of the shelf, at a depth of about 100 m (Fig. 9L). A minor extension of this group onto the shelf occurs in the area of higher nitrogen values.

Fence diagrams illustrate very well the dominant quantitative aspects of faunal-outfall relationships (Fig. 10). In specimens/g and especially % of total and living population, Buliminella elegantissima forms an abundance aureole around the Orange County outfall with a small depressed zone at the outfall point. This aureole effect is approximately one km in breadth on the northwest and southwest trends and more than two km in breadth on the northeast and southeast trends, the latter being directly in line with the main track of the sewage field. Trochammina pacifica plays a minor role in the outfall area. A group of six species comprises the Nonionella scapha basispinata group (Table 1), illustrating rather reduced values in no./g and % in the outfall area. A high percentage of this group at the outfall is misleading because of a very sparse fauna, as noted by the no./g (Fig. 10). A Buccella frigida group (Table 1) is made up of 8 species that appear to be most intolerant of the outfall conditions; this group attains considerable significance more than one km from the outfall, especially seaward.

FIG. 10. Fence diagrams illustrating trends in dominant faunal parameters across the Orange County outfall area. Note that Buliminella elegantissima comprises between 50 and 100% of the live population in an abundance aureole surrounding the outfall. Trochammina pacifica, an arenaceous foraminifer, is insignificant at the outfall. Species of the Nonionella scapha basispinata and Buccella frigida groups are given in Table 1. Apparent abundance of the Nonionella group at the outfall is based upon a very small population.

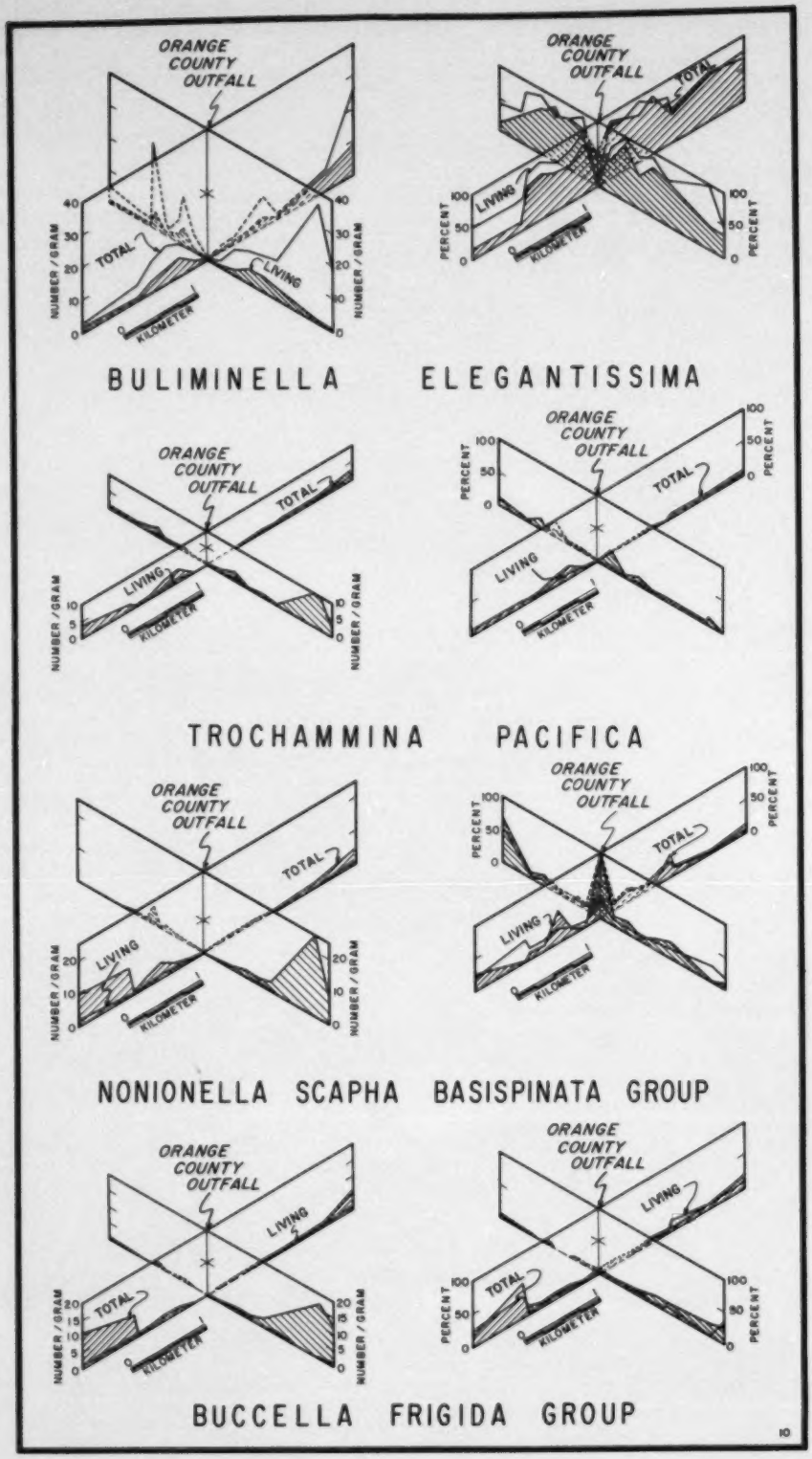

ORANGE COUNTY OUTFALL
TOTAL
LIVING
NUMBER / GRAM
PERCENT
KILOMETER
BULIMINELLA ELEGANTISSIMA
TROCHAMMINA PACIFICA
NONIONELLA SCAPHA BASISPINATA GROUP
BUCCELLA FRIGIDA GROUP
10

TABLE 1.--Foraminiferal species comprising the Nonionella scapha basispinata and Buccella frigida groups, Orange County outfall area, California

Nonionella scapha basispinata group
Discorbis columbiensis Cushman
Eggerella advena (Cushman)
Elphidium poeyanum spinatum Cushman and Valentine
Elphidium poeyanum translucens Natland
Fissurina lucida (Williamson)
Nonionella scapha basispinata (Cushman and Moyer)
Buccella frigida group
Buccella frigida (Cushman)
Bulimina marginata denudata Cushman and Parker
Elphidium poeyanum tumidum Natland
Haplophragmoides advenum Cushman
Alveolophragmium columbiense columbiense (Cushman)
Alveolophragmium columbiense vars.
Nonionella miocenica stella Cushman and Moyer
Rotorbinella lomaensis (Bandy)

SUMMARY AND CONCLUSIONS

Orange County outfall releases about 284 x 10^6 liters of effluent daily to the coastal waters of Orange County, California; ultimate discharge may reach 800 x 10^6 liters/day in the future due to increase in population. Sediments of the inner part of the shelf are sands, those on the central and outer shelf are silty sands and sandy silts, and sediments of the upper bathyal zone are silts and clays. Temperature and water depth change progressively with increasing distance from shore; sediments, calcium carbonate content, and nitrogen content do not change regularly offshore. Thus, it is possible to identify some faunal changes with sediment parameters and others with changes in water depth. Sediments are mostly olive green to gray in color; with increased effluent in future years it is possible that there will be a change under the sewage field to black sediments high in sulfides (hydrotroilite, etc.) as is now true under the sewage field at the Los Angeles County outfall. Maximum percentages of calcium carbonate on the shelf are somewhat over 5%, maximum values for nitrogen are between 0.03 and 0.05%.

Comparatively, the Laguna Beach outfall (Fig. 1) is small and is characterized by an abundance aureole of calcareous foraminifera living at the outfall; the Orange County outfall is of intermediate size and has a much larger abundance aureole of living foraminifera surrounding the outfall, but with a small depressed zone at the outfall point; Los Angeles County outfall is very large and has a correspondingly huge sewage field under which is a dead zone with no living foraminifera (polychaetes are abundant in the dead zone) and segments of an abundance aureole bound the edges of the dead zone. Volume of effluent discharged at the Orange County outfall has increased from about

102 x 10^6 liters/day in 1955 to the present volume of about 284 x 10^6 liters/day (Carollo 1962; Engineering-Science 1961). It is predicted that effluent discharge will reach 790 x 10^6 liters/day in the years 1979-80 (Carollo 1962). Polychaete abundance, now mostly restricted to the head of Newport submarine canyon, will probably expand toward the outfall into the sediments below the sewage field by that time.

Planktonic foraminifera become unusually abundant in the waters surrounding the outfall in contrast to the very low values on the shelf in most areas. Calcareous perforate foraminifera are more than 8 times as abundant as other types over most of the shelf area in the living population; somewhat greater prominence of arenaceous types in the dead assemblages of the central shelf suggests the calcareous forms are undergoing gradual postdepositional solution.

Buliminella elegantissima shows a marked increase in abundance near the Orange County outfall and along the track of the sewage field. This species is not only tolerant of the existing conditions, but its productivity is apparently favored by the effluent field in various depths of 24 m at the Laguna Beach outfall (Bandy, Ingle, and Resig 1964a), 61 m at the Los Angeles County outfall (Bandy, Ingle, and Resig 1964b), and at 18 m at the Orange County outfall. Most other benthic foraminifera show a decline near the outfall and within the area covered by the sewage field.

The arenaceous forms, Trochammina and Eggerella, are most abundant on silty sand and they appear to be controlled by sediment type rather than water depth within the shelf waters. Nonionella, a calcareous genus, is represented by considerable numbers of specimens on the central and outer shelf on sandy silts and silty sands; the Nonionella

group (Table 1) decreases markedly toward outfall areas, especially those of large volume.

Bulimina marginata denudata is abundant on the outer edge of the shelf in sediments with nitrogen values in excess of 0.03%; it is known to occur in lagoonal sediments with similar higher nitrogen values. With increased volume of effluent, it is to be expected that higher nitrogen values will occur in the outfall area and this will lead to the expansion of Bulimina marginata denudata there. A shelf-edge group appears at the edge of the shelf and becomes dominant in the uppermost bathyal zone on a substrate of silt.

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